Contract No. IWM06073

Technical Approach for the Life Cycle Assessment and Economic Analysis of Organic Waste Management and Greenhouse Gas Reduction Options

January 6, 2009

Submitted to

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1 Background

The California Integrated Waste Management Board (hereafter referred to as the Board) estimates that organics comprise approximately 73 percent[1] of the State's municipal solid waste (MSW) stream, including food scraps, yard trimmings, wood waste, and mixed paper. This statistic established organics management as a top priority for the Board[2]. Organic waste is also important in the context of GHG emissions and climate action plans because it creates methane in landfills, which are the largest source of anthropogenic methane emissions in the United States.

The RTI International Team (including subcontractors R.W. Beck, Matthew Cotton and Sally Brown) is assisting the Board in its efforts to achieve GHG emission reductions while striving toward zero waste and promoting sustainability by analyzing alternatives for the management of the organic fraction of MSW. The project will provide data and information to the Board to assist in considering and developing policies for organics waste management efforts in the coming years, including such controversial issues as the role of conversion technologies (e.g., anaerobic digestion) and the use of organic waste as alternative daily cover (ADC).

This memorandum contains a detailed working description of the technical approach for completing the "Life Cycle Assessment (LCA) of Organic Diversion Alternatives and Economic Analysis of Greenhouse Gas (GHG) Reduction Options" study. The approach is a working approach that will be updated over the time period of the project as more information is made available and/or developed.

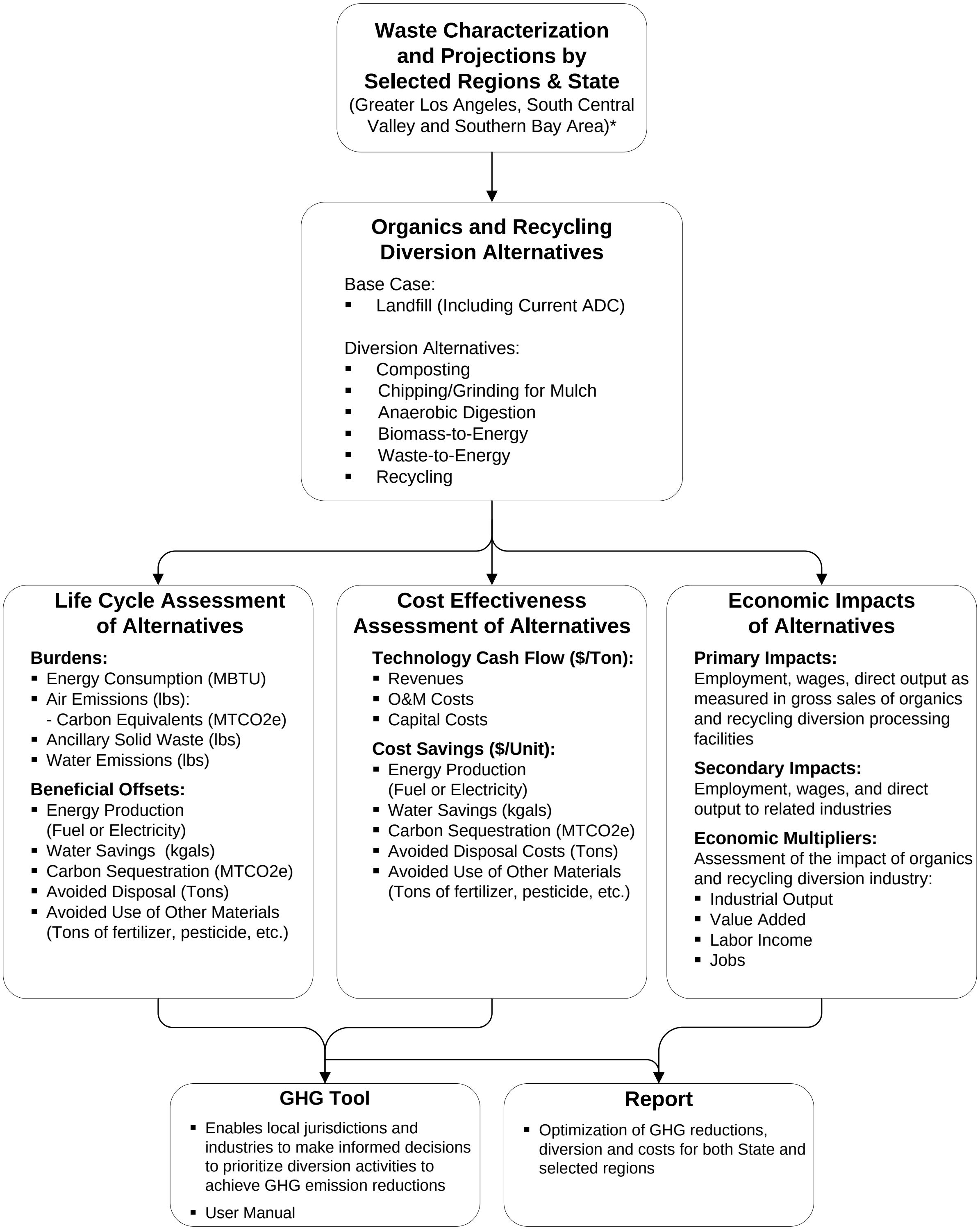
This project will be completed in 15 tasks as described in the Board's Statement of Work (SOW). These tasks were grouped by the RTI Team into the following project parts: Communication and Work Plan; LCA; Economic Analysis; GHG Tool; and the Final Report.

This memorandum focuses on the LCA, Economic Analysis and GHG Tool portions of the project and is organized into the following sections:

- Section 1—Overall Goals and Scope
- Section 2—Life Cycle Assessment
- Section 3—Economic Analysis
- Section 4—GHG Tool

Figure 1 illustrates the main project components and overall flow. The two main products of the project will include: (1) a study report analyzing the cost and LCA/GHG emissions for diversion alternatives for the state and select regions within the state, and (2) a GHG Tool intended for application to any region of the state.

[1] Includes all organic based materials in the California waste stream and not just the portion readily compostable.
[2] See: www.ciwmb.ca.gov/boardinfo/strategicplan/2007/sd06.htm



*Counties within the Selected Regions:
Greater Los Angeles Region – Los Angeles, Orange, Riverside and San Bernardino
South Central Valley Region – Madera, Fresno, Kings, Tulare and Kern
Southern Bay Region – San Francisco, San Mateo, Santa Clara, Alameda and Contra Costa

Figure 1. Overall Project Components and Flow.

2 Overall Project Goals and Scope

The goals of the LCA are to identify and quantify (to the fullest extent possible) GHG emissions and the emission reduction potentials associated with implementing defined diversion alternatives. The goals of the economic analysis are to quantify costs and cost savings, and the diversion potential of recycling and diversion alternatives. The economic analysis will also aim to quantify which diversion alternatives and recycling options (or combinations of these) are appropriate for specific California regions so that GHG emission reductions can be met in the most cost-effective manner and zero waste achieved.

The goal of the study is not to make absolute conclusions about the environmental (e.g., GHG) and economic preference of diversion alternatives. Rather, the goal is to better understand the potential relative environmental (e.g., GHG) and economic performance that may result from increasing diversion of waste to the alternatives.

In this section, the overall scope and boundaries of the study are defined. These are intended to apply to both the LCA and economic analysis, unless otherwise specified. Aspects specific to the LCA and economic analysis portions of the study are described in detail in Sections 3 and 4.

2.1 System Function and Functional Unit

The function of the system under study is to divert organics and specific recyclable components of MSW from disposal in a landfill. The functional unit is the management of a given quantity and composition of MSW disposed for the entire state or for defined regions under study. Section 2.4 outlines the waste tonnages and compositions that are being used in the study. Results will be presented on a total and per-ton basis to assist comparison between regions.

2.2 Geographic Boundaries

The study will be conducted on a statewide basis and also for specified regions to capture any potential regional differences and their impact on the LCA and/or economic analysis results. The regions and the counties they include are as follows:

- **Greater Los Angeles (GLA) Region:** includes the counties of Los Angeles, Orange, Riverside, and San Bernardino.
- **Southern Central Valley (SCV) Region:** includes the counties of Fresno, Kern, Kings, Madera, and Tulare.
- **Southern Bay (SBA) Region:** includes the counties of Alameda, Contra Costa, San Francisco, San Mateo, and Santa Clara.

Note that the geographic boundaries for the LCA and economic analysis portion of this project are different from the geographic boundaries of the GHG tool to be developed. The GHG Tool will include statewide average data for key GHG-related parameters and will allow users to input region-specific information as available.

2.3 Time Scale Boundaries

The overall study will focus on 2006 as the base year and expand out to the year 2025 at five-year increments. The most recent data available from the Board is from 2006 and this year was therefore selected as the starting point. The year 2025 was selected as a forecasting date to be consistent with other climate initiatives in the state such as the Local Government Operation Protocol[3]. Waste tonnages, composition, and other aspects (e.g., energy prices, recyclables prices, and compost product prices) are altered, as possible and appropriate, to reflect changes over time.

2.4 Waste Tonnage and Composition

According to the Board and Local Government Central[4], the 2006 statewide diversion rate was 54 percent. For this project, we needed to estimate the tonnage and composition of waste disposed for the years 2006 (baseline year) through 2025 for the state and regions under study. The Board compiled these data for the project using their Disposal Reporting System (DRS) database and information obtained from the 2004 Statewide Waste Characterization Study (Cascadia, 2004). These data included waste disposed at landfills and WTE facilities in the regions and the state. It also included waste that is disposed in other regions and states (i.e., exported waste) and alternative daily cover (ADC) from green waste and compost.

The historic (1998 to 2006) and future projected statewide and regional disposal tonnages are shown in **Table 1**. Future disposal tonnage projections were estimated by using a straight-line trend of the historic disposal tonnage data. These trend lines are shown for the state and three regions in **Figures 2 through 5**. Disposal tonnage data for each year from 2007 to 2025 were then determined using the linear best-fit trend line in Excel.

Figures 6 to 13 show the disposal waste tonnages and compositions using the data that the board compiled and adjusted to exclude the waste that is disposed at WTE facilities. In this study, WTE processes are considered diversion alternatives. The tonnage managed in the state WTE facilities: Commerce Refuse to Energy Incinerator (104,306 tons/yr) and Southeast Resource Recovery Facility (SERRF) (503,042 tons/yr) both in the Greater Los Angeles Region; and Covanta Stanislaus Inc. (233, 663 tons/yr) in Stanislaus County was then subtracted from the corresponding region and the statewide tonnage. The resulting values are presented in the figures.

Tables 2 to 5 were created according to the objectives of this study. Since the study is focused on diversion of organics, including lumber from construction and demolition (C&D) material, and traditional recyclables (i.e., paper, plastic, glass, metal), these waste categories are included in the tables. Other C&D waste, electronics, special, mixed, and household hazardous wastes are excluded from the study and thus the state and regional tonnages and waste composition data have been adjusted to remove these items as observed in the tables. ADC is considered diversion by statute but tonnages of greenwaste ADC and compost ADC are included in all tables and figures since the study will evaluate their GHG impacts.

For purposes of the study, it is assumed that the composition of waste will not change significantly in future years out to 2025. As the results of the LCA and Economic Analysis are developed and analyzed, the sensitivity of this assumption on study results will be addressed. In addition, the development of the GHG Tool, as part of this project, will enable users to change the waste tonnage and composition to reflect actual conditions.

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[3] See: http://www.climateregistry.org/resources/docs/protocols/progress/local-government/draft-lgo-protocol-061908.pdf

[4] See: http://www.ciwmb.ca.gov/LGCentral/Rates/Graphs/RateTable.htm

Table 1. Statewide and Regional Waste Disposal Tonnage Projections including ADC*

Year	Statewide Tonnage	Greater Los Angeles Region Tonnage	South Central Valley Region Tonnage	Southern Bay Region Tonnage
1998	39,212,251	19,926,149	1,902,744	6,212,036
1999	39,701,846	20,093,084	1,943,130	6,251,200
2000	41,129,748	21,145,268	1,960,929	6,247,976
2001	42,447,869	21,658,739	1,955,769	6,187,143
2002	42,467,975	21,677,041	2,035,805	5,830,583
2003	44,540,790	22,643,291	2,406,458	5,737,847
2004	45,638,708	23,258,146	2,337,134	5,849,185
2005	48,004,103	24,974,228	2,454,533	5,922,816
2006	45,000,511	22,513,864	2,495,367	5,860,950
2010	51,016,510	26,015,036	2,846,803	5,526,232
2015	55,947,398	28,532,086	3,272,453	5,223,201
2020	60,878,286	31,049,136	3,698,103	4,920,169
2025	65,809,185	33,566,187	4,123,753	4,617,145

*Includes waste managed at WTE facilities, exported waste, greenwaste ADC and compost ADC. ADC is considered diversion by statute but tonnages of greenwaste ADC and compost ADC are included in order to evaluate their green house gas impacts.

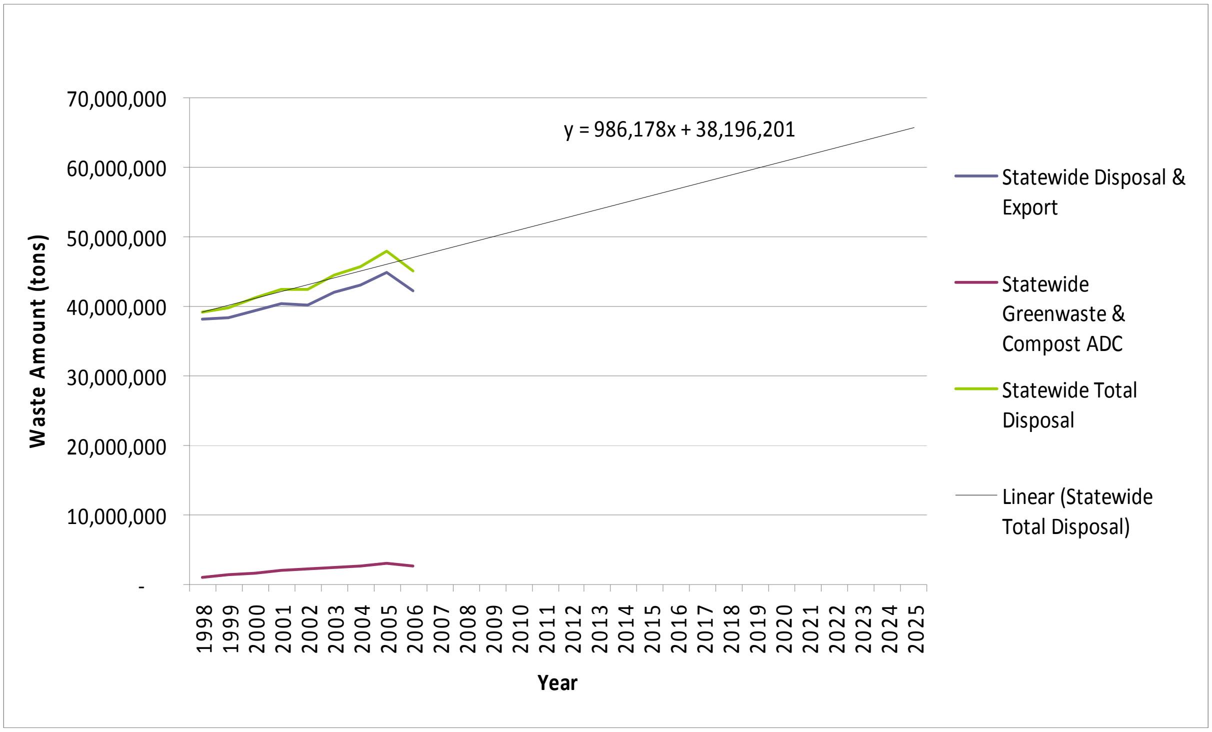


Figure 2. Statewide Disposal Tonnage Projection.

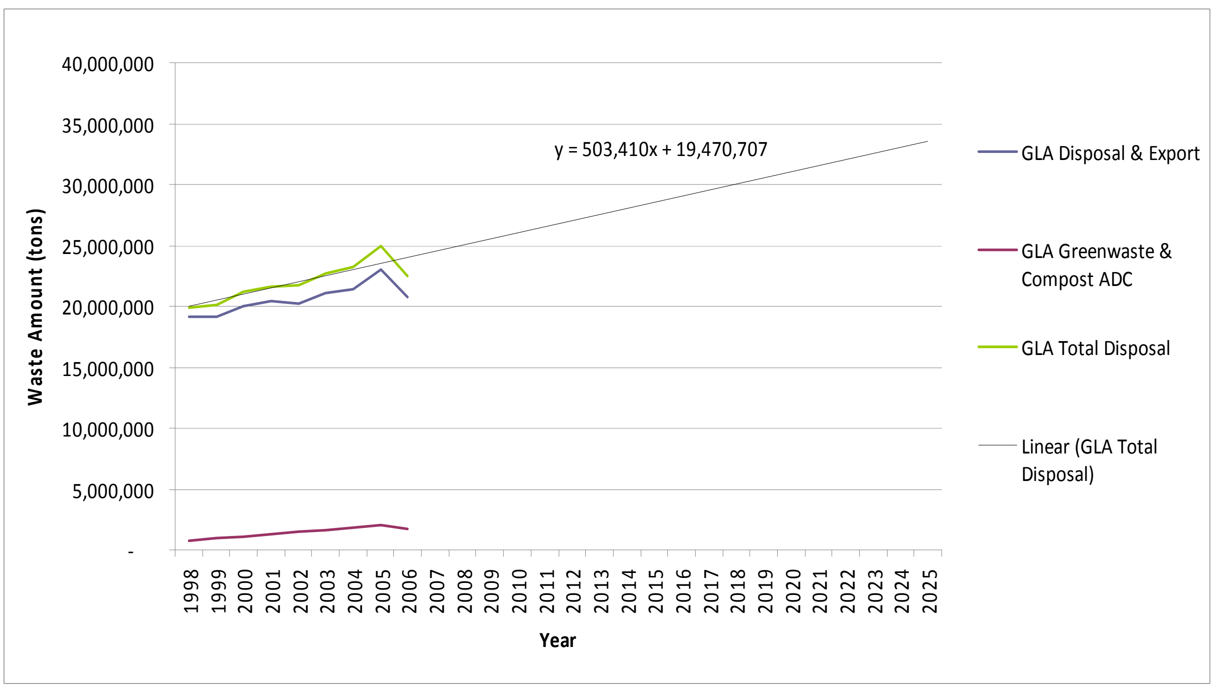


Figure 3. Greater Los Angeles Region Disposal Tonnage Projection.

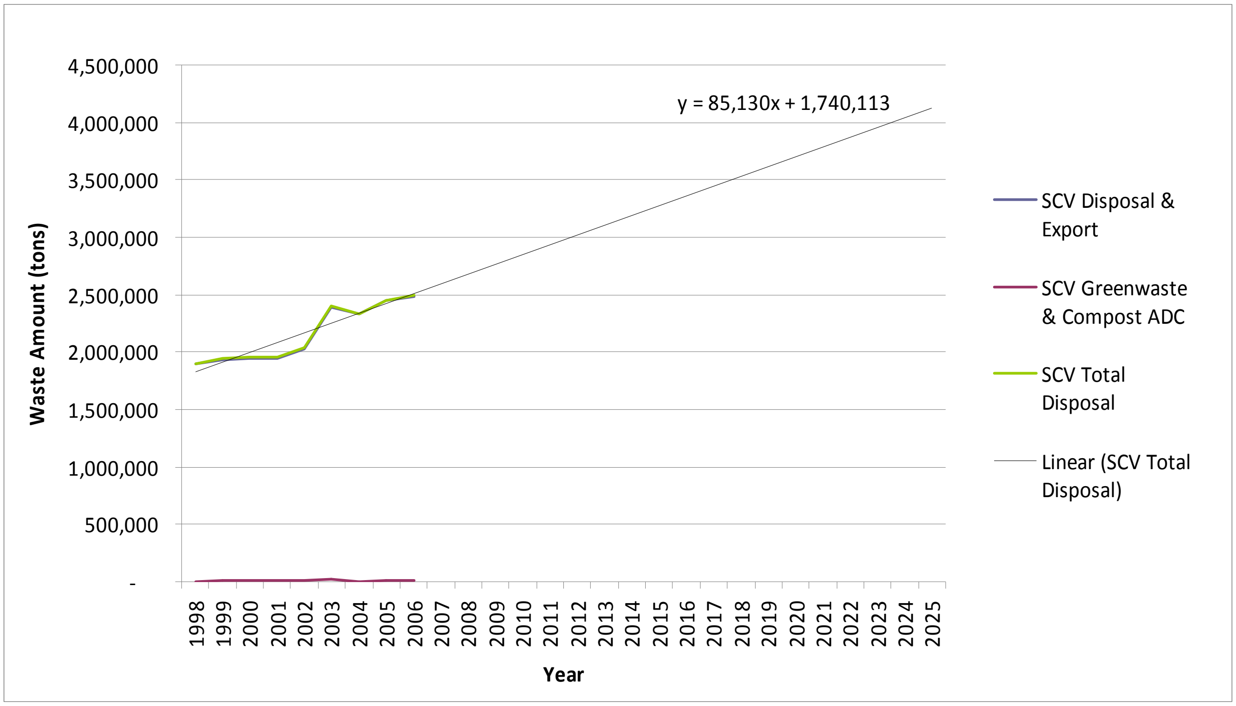


Figure 4. South Central Valley Region Disposal Tonnage Projection.

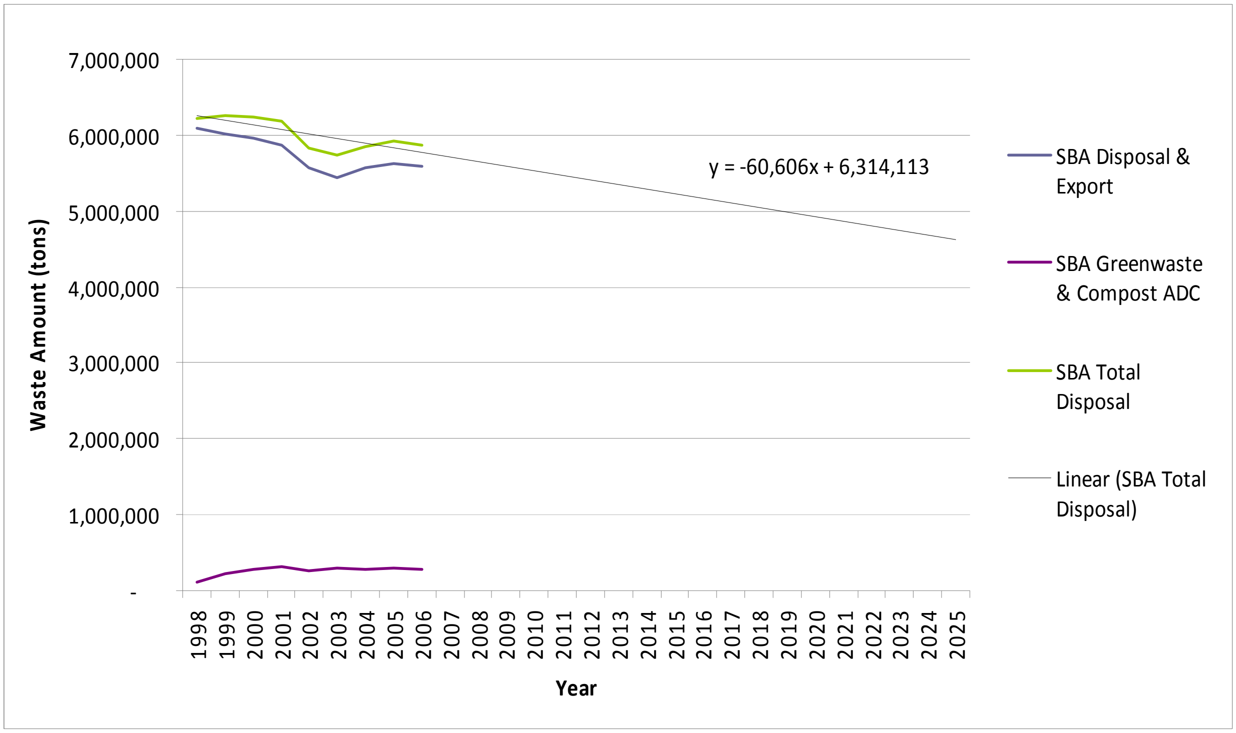
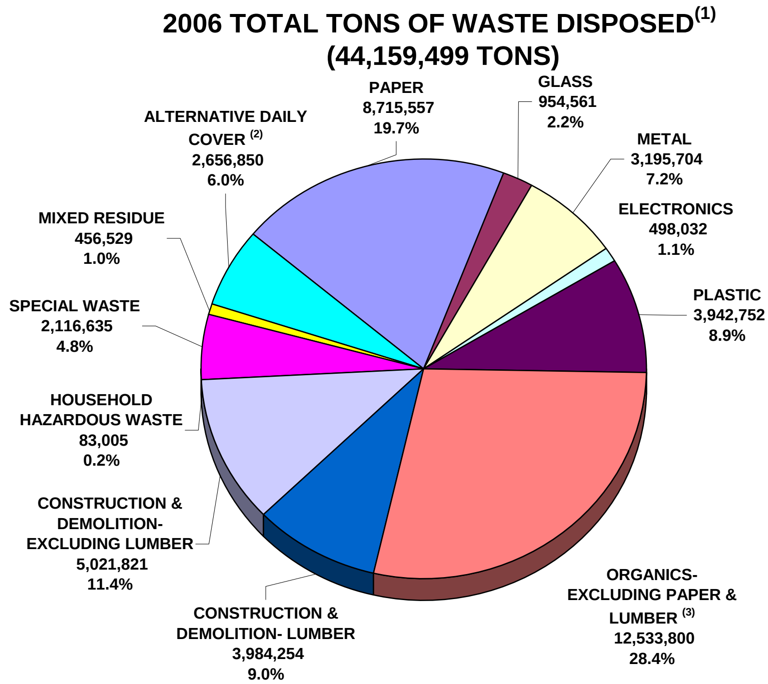


Figure 5. Southern Bay Region Disposal Tonnage Projection.

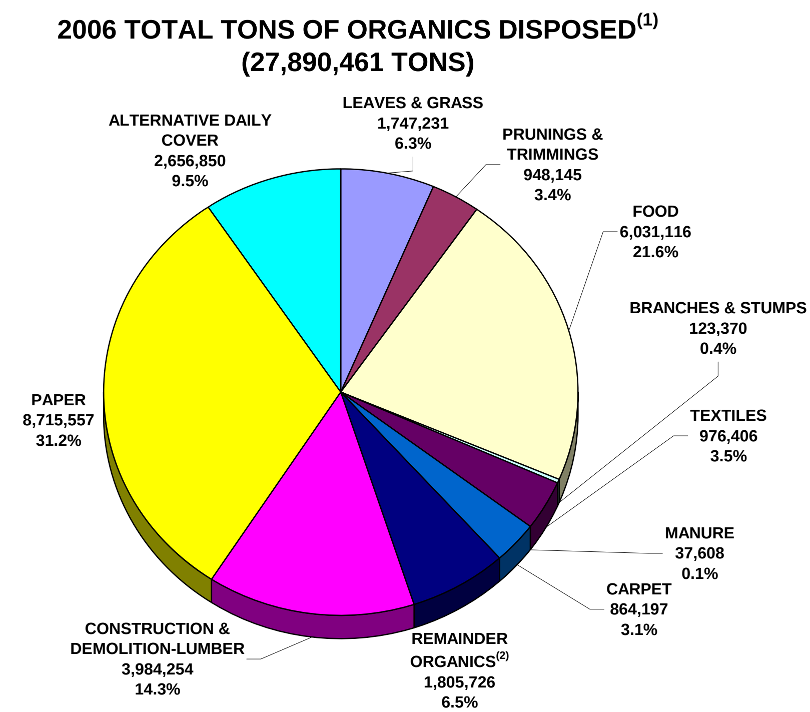


[1] Source: 2004 Statewide Waste Characterization Study- Cascadia (2004) (waste composition) and California Integrated Waste Management Board staff, June 27, 2008 (tonnage). Data were adjusted to exclude the waste managed via WTE.

[2] The alternative daily cover tonnage only includes green material and compost.

[3] Includes food, leaves, grass, prunings and trimmings, branches and stumps, agricultural crop residue, manure, textiles, carpet, and remainder/composite organics.

Figure 6. Statewide Composition and Tonnage of Disposed Waste.



[1] Source: 2004 Statewide Waste Characterization Study- Cascadia (2004) (waste composition) and California Integrated Waste Management Board staff, June 27, 2008 (tonnage). Data were adjusted to exclude the waste managed via WTE.

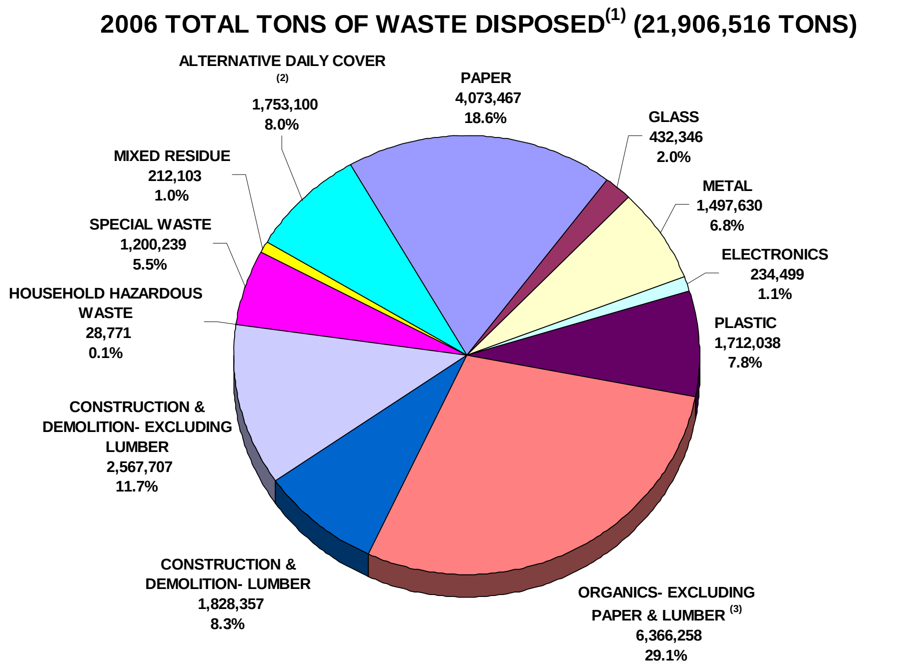
[2] Remainder organics include items such as leather, sawdust, cork, garden hoses, carpet padding, and diapers.

Figure 7. Statewide Composition and Tonnage of Disposed Organic Waste.

Table 2. Statewide Adjusted Composition and Tonnage of Disposed Waste Including ADC**

	Actual* Percent	Actual* Tonnage	Adjusted** Percent	Adjusted** Tonnage
Organics- Excluding Paper & Lumber	28.4%	12,533,800	34.8%	12,533,800
Paper	19.7%	8,715,557	24.2%	8,715,557
Glass	2.2%	954,561	2.7%	954,561
Metal	7.2%	3,195,704	8.9%	3,195,704
Electronics	1.1%	498,032	0%	
Plastic	8.9%	3,942,752	11.0%	3,942,752
Construction & Demolition-Lumber	9.0%	3,984,254	11.1%	3,984,254
Construction & Demolition-Excluding Lumber	11.4%	5,021,821	0%	
Household Hazardous Waste	0.2%	83,005	0%	
Special Waste	4.8%	2,116,635	0%	
Mixed Residue	1.0%	456,529	0%	
Alternative Daily Cover	6.0%	2,656,850	7.4%	2,656,850
Total Materials	**100.0%**	**44,159,500**	**100%**	**35,938,478**

*Actual values correspond to the values presented in Figures 6 and 7.
**Adjusted to remove waste items not included in the scope of this study.
Percentages may not total 100% due to rounding.

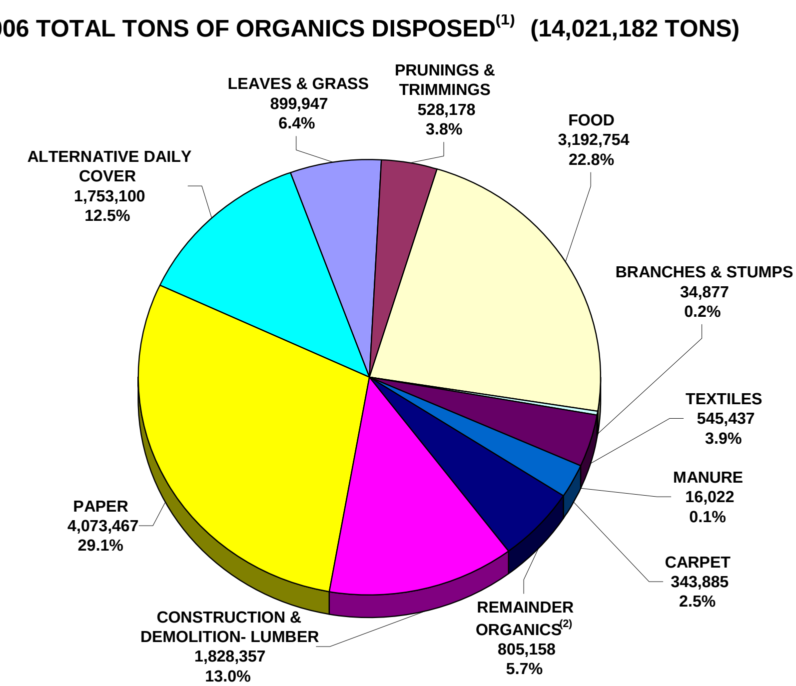


[1] Source: California Integrated Waste Management Board staff, April 25, 2008 (waste composition) and June 27, 2008 (tonnage). Data adjusted to exclude the waste that is managed via WTE.

[2] The alternative daily cover tonnage only includes green material and compost.

[3] Includes food, leaves, grass, prunings and trimmings, branches and stumps, agricultural crop residue, manure, textiles, carpet, and remainder/composite organics.

Figure 8. Composition and Tonnage of Waste Disposed in the Greater Los Angeles Region.



[1] Source: California Integrated Waste Management Board staff, March 14, 2008, April 25, 2008, and June 27, 2008.

[2] Remainder organics include items such as leather, sawdust, cork, garden hoses, carpet padding, and diapers.

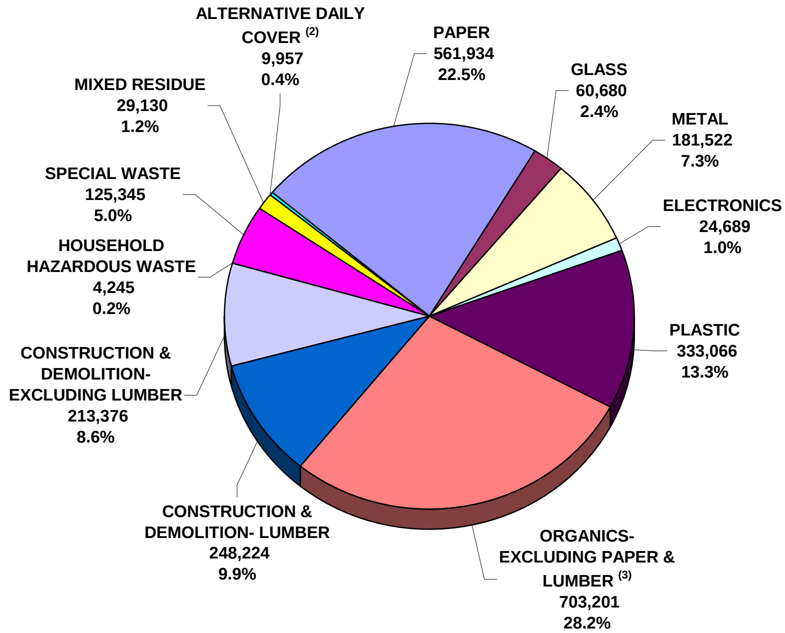
Figure 9. Composition and Tonnage of Organic Waste Disposed in the Greater Los Angeles Region.

Table 3. Adjusted Composition and Tonnage of Waste Disposed in the Greater Los Angeles Region

	Actual* Percent	Actual* Tonnage	Adjusted** Percent	Adjusted** Tonnage
Organics- Excluding Paper & Lumber	29.1%	6,366,258	36%	6,366,258
Paper	18.6%	4,073,467	23.1%	4,073,467
Glass	2.0%	432,346	2%	432,346
Metal	6.8%	1,497,630	8%	1,497,630
Electronics	1.1%	234,499	0%	
Plastic	7.8%	1,712,038	10%	1,712,038
Construction & Demolition- Lumber	8.3%	1,828,357	10%	1,828,357
Construction & Demolition- Excluding Lumber	11.7%	2,567,707	0%	
Household Hazardous Waste	0.1%	28,771	0%	
Special Waste	5.5%	1,200,239	0%	
Mixed Residue	1.0%	212,103	0%	
Alternative Daily Cover	8.0%	1,753,100	10%	1,753,100
Total Materials	**100%**	**21,906,516**	**100%**	**17,663,197**

*Actual values correspond to the values presented in Figures 8 and 9.
**Adjusted to remove waste items not included in the scope of this study.
Percentages may not total 100% due to rounding.

2006 TOTAL TONS OF WASTE DISPOSED[1] (2,495,367 TONS)



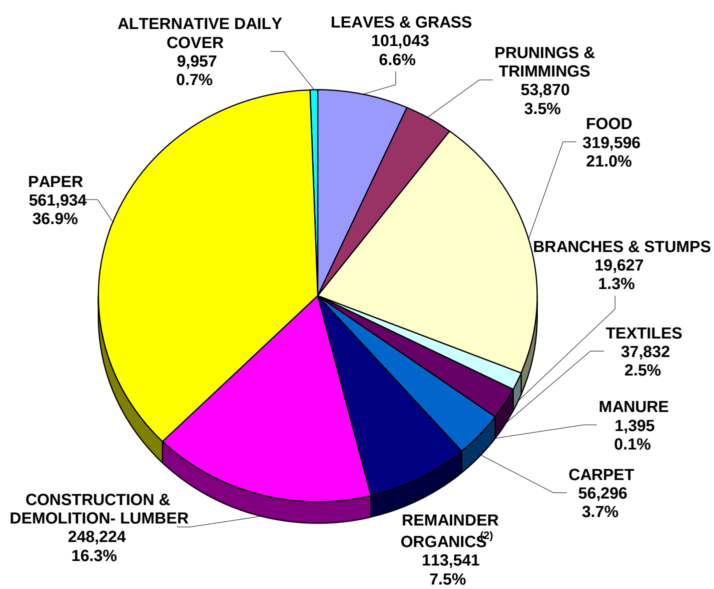
1 Source: California Integrated Waste Management Board staff, March 14, 2008 (waste composition) and June 27, 2008 (tonnage).

2 The alternative daily cover tonnage only includes green material and compost.

3 Includes food, leaves, grass, prunings and trimmings, branches and stumps, agricultural crop residue, manure, textiles, carpet, and remainder/composite organics.

Figure 10. Composition and Tonnage of Waste Disposed in the South Central Valley Region.

2006 TOTAL TONS OF ORGANICS DISPOSED [1] (1,523,315 TONS)



1 Source: California Integrated Waste Management Board staff, March 14, 2008, April 25, 2008, and June 27, 2008.

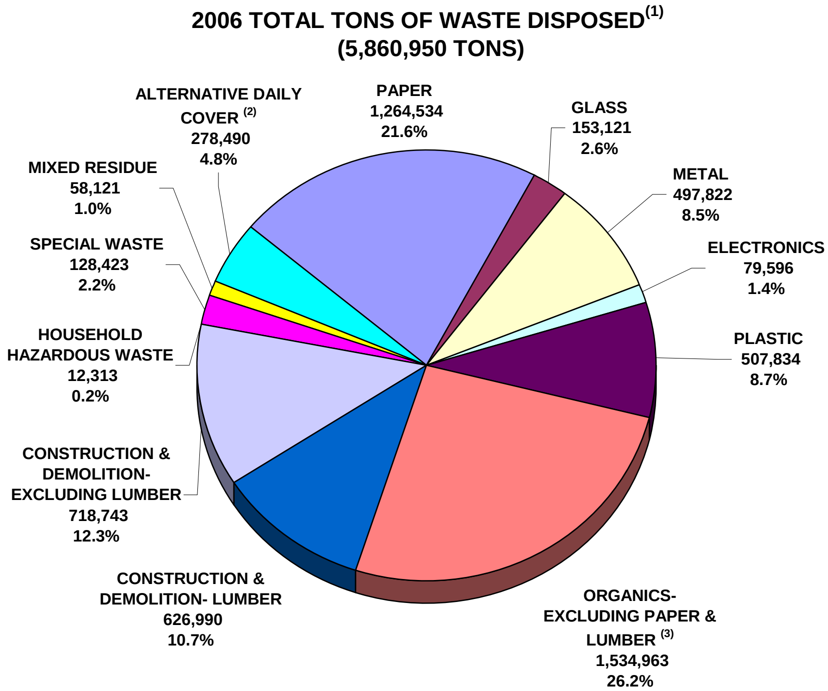
2 Remainder organics include items such as leather, sawdust, cork, garden hoses, carpet padding, and diapers.

Figure 11. Composition and Tonnage of Organic Waste Disposed in the South Central Valley Region.

Table 4. Adjusted Composition and Tonnage of Waste Disposed in the South Central Valley Region

	Actual* Percent	Actual* Tonnage	Adjusted** Percent	Adjusted** Tonnage
Organics- Excluding Paper & Lumber	28.2%	703,201	33.5%	703,201
Paper	22.5%	561,934	26.8%	561,934
Glass	2.4%	60,680	2.9%	60,680
Metal	7.3%	181,522	8.6%	181,522
Electronics	1.0%	24,689	0%	
Plastic	13.3%	333,066	15.9%	333,066
Construction & Demolition- Lumber	9.9%	248,224	11.8%	248,224
Construction & Demolition- Excluding Lumber	8.6%	213,376	0%	
Household Hazardous Waste	0.2%	4,245	0%	
Special Waste	5.0%	125,345	0%	
Mixed Residue	1.2%	29,130	0%	
Alternative Daily Cover	0.4%	9,957	0.5%	9,957
Total Materials	**100%**	**2,495,367**	**100.0%**	**2,098,583**

*Actual values correspond to the values presented in Figures 10 and 11.
**Adjusted to remove waste items not included in the scope of this study.
Percentages may not total 100% due to rounding.

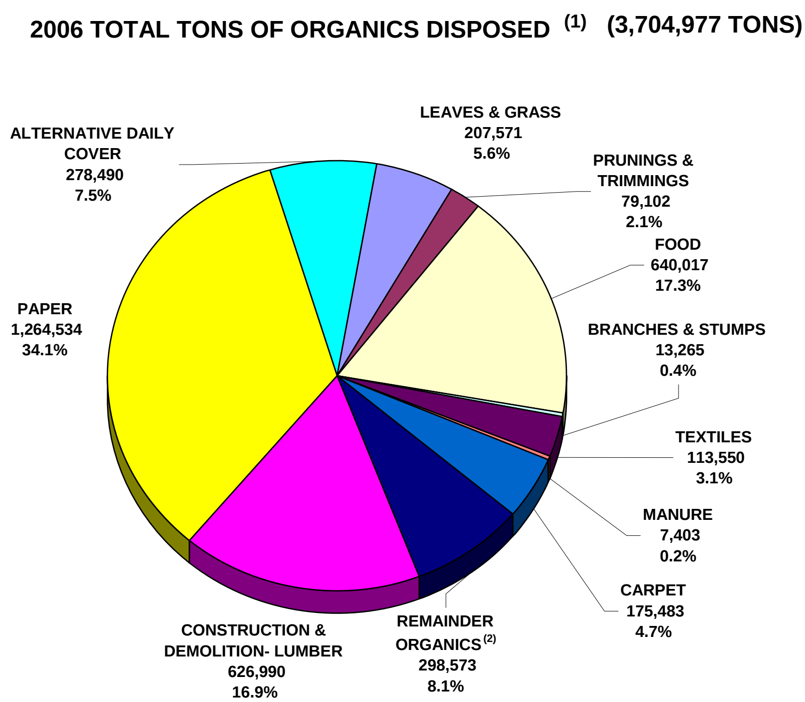


1 Source: California Integrated Waste Management Board staff, April 25, 2008 (waste composition) and June 27, 2008 (tonnage).

2 The alternative daily cover tonnage only includes green material and compost.

3 Includes food, leaves, grass, prunings and trimmings, branches and stumps, agricultural crop residue, manure, textiles, carpet, and remainder/composite organics.

Figure 12. Composition and Tonnage of Waste Disposed in the Southern Bay Region.



1 Source: California Integrated Waste Management Board staff, March 14, 2008, April 25, 2008, and June 27, 2008.

2 Remainder organics include items such as leather, sawdust, cork, garden hoses, carpet padding, and diapers.

Figure 13. Composition and Tonnage of Organic Waste Disposed in the Southern Bay Region.

Table 5. Adjusted Composition and Tonnage of Waste Disposed in the Southern Bay Region

	Actual* Percent	Actual* Tonnage	Adjusted** Percent	Adjusted** Tonnage
Organics- Excluding Paper & Lumber	26.2%	1,534,963	32%	1,534,963
Paper	21.6%	1,264,534	26%	1,264,534
Glass	2.6%	153,121	3%	153,121
Metal	8.5%	497,822	10%	497,822
Electronics	1.4%	79,596	0%	
Plastic	8.7%	507,834	10%	507,834
Construction & Demolition- Lumber	10.7%	626,990	13%	626,990
Construction & Demolition- Excluding Lumber	12.3%	718,743	0%	
Household Hazardous Waste	0.2%	12,313	0%	
Special Waste	2.2%	128,423	0%	
Mixed Residue	1.0%	58,121	0%	
Alternative Daily Cover	4.8%	278,490	6%	278,490
Total Materials	**100%**	**5,860,950**	**100%**	**4,863,754**

*Actual values correspond to the values presented in Figures 10 and 11.
**Adjusted to remove waste items not included in the scope of this study.
Percentages may not total 100% due to rounding.

2.5 Diversion Alternatives Under Study

Diversion alternatives include any recycling or non-recycling process that diverts MSW, and particularly organics, from landfill disposal. An example of an organic diversion alternative is composting, where carbon-based organic materials could be diverted from the landfill and turned into compost product. If the compost product is applied to agricultural fields, one beneficial "offset" is that fertilizer application may be reduced. The reduced application of fertilizer, in turn, has the effect of less fertilizer manufacturing, energy use, and emissions. Additional beneficial "offsets" of composting might include reduced pesticide, herbicide, and water inputs, as well as long-term soil carbon storage.

RTI used qualitative information and worked with the Board Contract Manager to identify potential diversion alternatives for consideration where quantitative data were not available regarding preliminary, order-of-magnitude information about GHG emissions and potential beneficial offsets. As a base case, landfill disposal including current ADC practice is used. The final diversion alternatives that are serving as the basis for conducting the LCA and the economic analysis, as well as the GHG Tool, include the following:

- Windrow composting for soil amendment and stabilized landfill cover
- Chipping/grinding for mulch
- Anaerobic digestion
- Biomass-to-energy (electricity and/or fuels)
- Waste-to-energy
- Recycling (glass, paper, plastic, metals)

A more comprehensive list of potential diversion alternatives was initially identified and evaluated for inclusion in the study. Other alternatives that were considered but not included in the study consist of the following:

- Processing into animal feed and/or fertilizer,
- Acid hydrolysis to ethanol
- Gasification to electricity

A key aspect of the decision-making process about what alternatives to include was identifying alternatives that can achieve the largest rate of return in terms of GHG emission reductions. For all diversion alternatives considered, information was compiled about potential beneficial offsets (see **Attachment A**).

The newer, emerging technologies such as gasification and hydrolysis were excluded from the study because reliable data for commercial-scale facilities that handle MSW do not exist. Other alternatives, such as processing into animal feed, were thought to be specialty processes and are not significant for this study.

To conduct the life cycle and economic analyses, diversion alternative scenarios must be defined. As a first-level and more hypothetical analysis, we will model all waste as being diverted to each alternative. However, it is unlikely that any one alternative would be implemented (instantaneously) to meet diversion goals. To develop more realistic scenarios the following approach is being taken:

1. Review facility data to assess the currently used and available capacity for each alternative by study region.
2. Review facility data to determine the average size (capacity) facility for each alternative by study region.
3. Project the implementation of new facilities at the average facility size for different alternatives in each study region over time out to year 2025.
4. Develop a mix of facilities to be implemented in each study region over time out to year 2025.

Although this scenario approach will still be hypothetical, it will be based on more realistic constraints of facility implementation over time. Based on our experience in conducting scenario analyses for waste management systems, it will likely be necessary to address the scenario designs after reviewing preliminary results and possibly refine and/or develop additional scenarios to resolve specific issues (e.g., variations in facility designs, co-location of facilities).

3 Life Cycle Assessment (LCA)

LCA is a technique for assessing the environmental aspects and potential impacts of a system from raw materials acquisition through production, use, and disposal. According to the internationally accepted ISO 14040 standard (see Section 3.2), conducting an LCA includes compiling an inventory of relevant inputs and outputs of a system, evaluating the potential environmental and health impacts of those inputs and outputs, and interpreting the results in relation to the objectives of the study. LCA provides a systematic and standard methodology for characterizing the environmental aspects and potential impacts of diversion alternatives. **Figure 14** shows a life cycle flow diagram for organics. The methodology for conducting the LCA of diversion alternatives will include all stages of the waste life cycle and will be based on the mass flow of materials and energy in and out, emissions, and associated impacts of the different unit processes included within the life cycle.

Our approach to completing the LCA focuses on reviewing existing MSW/LCA/GHG tools [5] to identify desirable features for estimating GHG emissions associated with diversion alternatives; identifying possible diversion alternatives and associated product, energy, or other "offsets"; clearly defining the scope and boundary for the LCA; collecting data to fill gaps for alternatives; and conducting the LCA for organic diversion alternatives (and combinations of alternatives) based on statewide and regional characteristics. In general, we will strive to conduct the LCA so that it conforms with ISO 14040 requirements.

To facilitate and accelerate the completion of the LCA, we are utilizing RTI's in-house Municipal Solid Waste Decision Support Tool (MSW DST). RTI collaborated with EPA to develop the MSW DST to assist local governments and other solid waste planners in evaluating the cost and life cycle environmental aspects of alternative MSW management strategies. The waste management processes currently included in the MSW DST are collection, transfer stations, recycling, mixed municipal and yard waste composting, waste-to-energy, land disposal (conventional, ash, and bioreactor) and source reduction. This peer-reviewed tool, and the data it includes, will be used to quantify GHG emission reductions for diversion strategies. Data and methods in the MSW DST will be supplemented with data and methods from other sources,

[5] See: http://www.ciwmb.ca.gov/Climate/Organics/LifeCycle/LCAToolEval.pdf

including tools initially screened, primary data collected for compost product application and characterization of beneficial offsets as part of this project.

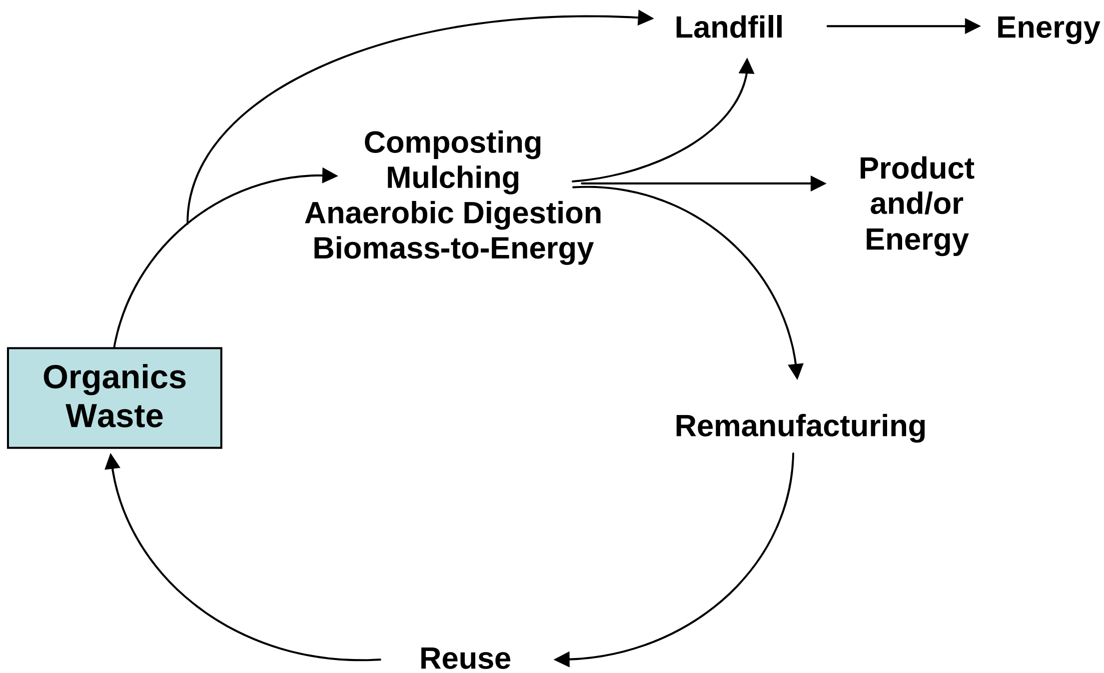


Figure 14. Life Cycle Diagram for Organics Diversion.

3.1 LCA Goal Definition and Scope

The goals/objectives of the LCA portion of the project are to identify and quantify (to the fullest extent possible) GHG emissions and the emissions reduction potentials associated with implementing defined diversion alternatives at state and regional levels. The defining feature of an LCA is that it captures multi-media environmental impacts associated with all upstream and downstream stages of a system. This feature enables analysts to assess not only the total environmental profile of a system, but also to identify where impacts may be shifted from one life cycle stage to another or from one media to another. Life cycle approaches shift environmental management from traditional “end-of-pipe” or “gate-to-gate” approaches to a more proactive and preventive approach.

All activities that have a bearing on the management of solid waste, from collection through transportation, recovery and separation of materials, treatment, and disposal, are included in the LCA boundaries. It will be assumed that organic material enters the system boundaries when it is set out (or dropped off) for collection. Therefore, the life cycle burdens associated with the production of garbage bags, garbage cans, compost, and recycling bins will not be included in the study. Similarly, the transport of waste by residents to a drop-off facility will not be included.

The functional elements of solid waste management include numerous pieces of capital equipment, from refuse collection vehicles to balers for recycled materials to major equipment at composting and combustion facilities. Resource and energy consumption and environmental releases associated with the operation of equipment and facilities will be included in the study.

For example, energy (fuel) consumed during the operation of waste collection vehicles will be included. We also will include electricity consumed for operation of the office through which the vehicle routes are developed and the collection workers are supervised. Activities associated with the fabrication of capital equipment, such as the collection vehicles themselves, will not be included.

The resource and energy consumption and environmental releases associated with producing the material and energy inputs will be included in the study. For example, the resources and environmental releases associated with the production of lime or other materials used for air pollution control will be included, as well as the production of diesel fuel consumed by collection vehicles.

Where a material was recovered and recycled, the resource and energy consumption and environmental releases associated with the manufacture of a new product will be calculated and included in the study. We will assume closed-loop recycling processes (e.g., recovered newsprint is made into new newsprint). These parameters will then be compared against parameters for manufacturing the product using virgin resources to estimate net resource and energy consumption and environmental releases. This procedure will also be applied to energy recovery from processes, such as biomass-to-energy or landfill gas-to-energy, as well as to compost product application.

Another system boundary will be set at the waste treatment and disposal. Where liquid wastes are generated and require treatment (usually in a publicly owned treatment works), the resource and energy consumption and environmental releases associated with the treatment process will be included. For example, if biological oxygen demand (BOD) from an anaerobic digestion facility is treated in an aerobic biological wastewater treatment facility, then energy is consumed to supply adequate oxygen for waste treatment. Likewise, if a solid waste is produced that requires burial, energy is consumed in the transport of that waste to a landfill during its burial (for example, bulldozer) and after its burial (for example, gas collection and leachate treatment systems) in the landfill. Also, where compost was applied to the land, volatile organic chemical (VOC) and nitrous oxide (N_2O) emissions will be included in the study.

3.2 LCA Standards

The life cycle concept and more formal LCA have evolved through an increasing awareness that a comprehensive view of production systems leads to environmentally friendly design and decision-making. The process for conducting an LCA has recently been standardized by the International Standards Organization (ISO) and provides a useful framework and methodology for estimating and comparing the environmental performance of systems. The following ISO standards are available:

- ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework (1997)
- ISO 14041: Environmental Management – Life Cycle Assessment – Goal and Scope Definition and Inventory Analysis (1998)
- ISO 14042: Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment (2000)
- ISO 14043: Environmental Management – Life Cycle Assessment – Life Cycle Interpretation (2000)

Although these standards provide requirements and recommendations in terms of what an LCA should include, they recognize that the actual methods used and level of detail employed in the assessment will vary by study. In general, the goals of the LCA will drive the level of complexity and detail required in the study. The most rigorous level of detail is required for cross-product comparative assessments. For this study, using California statewide average and region-specific information for diversion alternatives is desired.

3.3 Key Outputs from the LCA

Key parameters that will be included in the output results of the LCA are defined by the Board in the SOW as follows:

- Energy consumption/production
- GHG emissions and emissions reductions
- CO_2 biogenic: results from the biodegradation or combustion of organic material
- CO_2 fossil: results from the combustion of fossil-fuel based products
- CH_4: results primarily from the anaerobic decomposition of organic material
- N_2O: results from the combustion of fossil-fuel based products
- Criteria air pollutants
- Carbon sequestration/storage
- Landfill diversion

The RTI team is collecting process, economic, and environmental data for existing facilities within the three study regions for each of the diversion alternatives. This task is expected to be completed by the end of January 2009. The data collected and supplemented with publicly available information will then be used to define the boundaries and key assumptions for each organic diversion alternative. The boundaries will include detailed process descriptions and process flow diagrams for each alternative to identify mass flows, energy and materials consumption, GHG emissions, products and by-products, and residual wastes. We will also highlight any preprocessing (e.g., autoclave, materials separation) steps that may be required, as well as any beneficial "offsets" (e.g., energy, usable products) generated and attributable to each of the alternatives. Once the preliminary boundaries have been defined, we will work with the Board and possibly with external critical reviewers/stakeholders to finalize the boundaries.

For each identified region, the RTI Team will identify existing and planned solid waste infrastructure. We will also work with officials and planners in each region to identify potential locations for future organic diversion alternatives (and/or combinations of facilities) for which infrastructure currently does not exist. Using the site information, RTI will prepare a geographic information system map overlaying the regional boundaries.

The RTI Team will develop algorithms for each organic diversion alternative to calculate the GHG emissions and other metrics as identified in the scope and boundaries for the LCA model. The algorithms will be spreadsheet-based (Microsoft Excel) equations that use design and operational information for each alternative to generate inventory and impact coefficients. We propose to design the algorithms so that the coefficients are calculated based on the mass and composition of organic waste input. By following this approach, the algorithms can be used to estimate statewide and regional GHG emissions, and will be able to handle unlimited combinations of alternatives. This approach is consistent with other process modules in RTI's

MSW DST and will allow for component-specific (e.g., mixed paper versus grass clippings) analysis.

Algorithms for calculating GHG emissions and emissions reductions will be based on international protocol (e.g., International Panel on Climate Change), as well as California-specific protocols (e.g., Climate Action Registry), so that the results may fit seamlessly into GHG reporting/certification programs and zero waste programs. With respect to issues likely to be particularly difficult and therefore controversial, such as the allocation of biogenic and non-biogenic GHG emissions, the RTI Team will work with Board staff to develop the best possible approaches.

3.4 LCA Data Collection Approach

For this project, a mix of secondary (existing data) and primary data is being collected. We will rely on secondary data sources as available to characterize the currently disposed fraction of MSW and diversion alternatives. From secondary sources, we will seek data that is of high quality, objective, well documented, and has been critically reviewed and/or verified. Our goal is to have high quality, scientifically based data for each diversion alternative. To this end, we are also supplementing the secondary data with primary data that is being collected from facilities. Our focus and goal for primary data collection is to obtain data that is based on actual practice for California-specific infrastructure, and specific diversion facility designs (e.g., anaerobic digestion).

To the extent possible, we will follow the ISO 14040 guidelines for assessing and reporting data quality for the following quality aspects:

- Time related coverage
- Geographical coverage
- Technology coverage
- Precision
- Completeness
- Representativeness
- Consistency
- Reproducibility

The goal of data collection for this project is to ensure that appropriate California statewide and regional data are collected to support comparable estimation of life cycle burdens (focusing on GHG emissions) for the diversion alternatives under study. Through previous work conducted by RTI, extensive life cycle data have already been collected or developed for waste management processes and more is planned for in this study. RTI's existing data include energy consumption, air emissions, water effluents, and solid waste for waste collection; transfer stations; materials recovery facilities; yard and mixed municipal waste composting; waste-to-energy combustion; landfill disposal; supporting life cycle operations of electrical energy production using national, regional, or user defined grids; fuels production (e.g., diesel fuel); virgin and recycled materials productions (e.g., glass containers); and transportation (e.g., over road haul). The data have been thoroughly peer reviewed and carefully documented to ensure transparency and, most importantly, allows us to focus on collecting or developing data specific to diversion alternatives in California.

As a starting point, existing algorithms included in the MSW DST will be used to generate GHG emission results for diversion alternatives. The existing algorithms and data were developed and peer-reviewed in 1994 and have since been refined and extensively quality checked. As appropriate, the algorithms will be updated to address key features identified in the MSW/LCA/GHG tool review and also regional- and/or technology-specific data collected.

In addition, the algorithms will be modified as appropriate to meet any GHG protocols required in California and other relevant climate change programs. Not only will using RTI's existing models as a starting point be valuable to the project for purposes of analyzing organic diversion alternatives, but will also provide a solid foundation and dataset for building the GHG tool as part of the project. This will also enable us to focus our effort on collecting and/or developing the best possible GHG-related data and methods for organic diversion alternatives and in particular, on quantifying "beneficial offsets" associated with the alternatives.

Table 6 summarizes the key sources of data and GHG algorithms planned for use in various waste management processes and other ancillary life cycle activities. One focus area for data development is to quantify composting and mulching related to "beneficial offsets." Existing data is available from the following sources:

- New South Wales, Australia Study
- WRATE (UK waste LCA model)
- WARM, (U.S. EPA waste and GHG calculator)

Because this existing data is more general (as in the case of WARM) or specific to conditions in other counties (as in the case of the Australian and UK studies), a dedicated data collection effort is planned for compost application and associated benefits. A separate data collection plan is being prepared for this effort.

Table 6. Key LCI/GHG Emissions Data Sources to be Used by Process/Activity

Process/Activity	Key Data Sources*	Algorithms for GHG Estimation*
Waste Collection	MSW DST using California and region specific input data.	Mass and volume and travel distance based approach to estimate fuel consumption and related GHG emissions.
Waste Transfer	MSW DST using California and region specific input data.	Mass and volume and travel distance based approach to estimate fuel consumption and related GHG emissions.
Recycling Facility (MRF)	MSW DST using California and region specific input data.	Mass and volume based approach to estimate energy consumption and related GHG emissions.
Recycling Offsets	WARM and MSW DST	Based on national average factors for material production processes.
Compost Facility	MSW DST using California and region specific input data.	Mass and volume based approach to estimate energy consumption and related GHG emissions.
Compost Beneficial Offsets	Developed via this project through site data collection.	TBD
Compost Carbon Sequestration	Developed via this project through site data collection and soil sampling/analysis	TBD

Process/Activity	Key Data Sources*	Algorithms for GHG Estimation*
WTE Offsets	MSW DST using California and region specific input data.	Based on regional electricity grid mix being offset.
Anaerobic Digestion	MSW DST using California and region specific input data.	Mass and volume based approach to estimate energy consumption and related GHG emissions.
Anaerobic Digestion Electricity Offsets	MSW DST using California and region specific input data.	Based on regional electricity grid mix being offset.
Anaerobic Digestion By-product Offsets	Developed via this project by estimation and use of publicly available data and information.	TBD
Anaerobic Digestion Carbon Sequestration	Developed via this project by estimation and use of publicly available data and information.	TBD
Mulch Facility	MSW DST using California and region specific input data.	Mass and volume based approach to estimate energy consumption and related GHG emissions.
Mulch Offsets	Developed via this project through site data collection.	TBD
Mulch Carbon Sequestration	Developed via this project through site data collection and soil sampling/analysis	TBD
Landfill Facility and Gas Production	MSW DST using California and region specific input data.	First-order decay model.
Landfill Electricity Offsets	MSW DST using California and region specific input data.	Based on regional electricity grid mix being offset.
Landfill Carbon Storage	WARM landfill carbon storage factors	Based on landfill carbon storage factors used in WARM.

*Key data sources and algorithms are preliminary and subject to change as new data information becomes available.

3.5 Key Assumptions and Limitations of the LCA

All key assumptions and limitations of the LCA will be carefully documented and presented in the final report. Assumptions and limitations will evolve as the LCA progresses and might include such aspects as:

- Facility design and operation specifications
- MSW composition and organics composition estimates
- Base and future year diversion scenarios
- Use of average, proxy or surrogate data
- GHG algorithms assumptions
- Assumptions and limitations in interpreting LCA results

3.6 LCA Critical Review

In general, critical reviews of LCAs are optional and typically based on the purpose and intended applications of the study. Critical review is required only for LCAs that are used to make comparative assertions. For this study, where we will ultimately be comparing the relative environmental and GHG impacts diversion alternatives, critical review is needed to ensure that the technical approach, methods, data, and results adequately satisfy the requirements of the study.

Three primary levels of critical review have been built into this study, including:

- Internal review of results
- Board review of the technical approach and results
- Stakeholder meetings and review of the technical approach and results

Comments from each level of review will be used to refine the study and frame the final report and GHG tool to be developed.

4 Economic Analysis

The purpose of the Economic Analysis is to provide the Board with a range of projected capital costs and operating costs, cost savings, and revenues (in 2006 U.S. dollars) for the organic and recycling diversion alternatives under study. The results for this task will be incorporated into the GHG tool to assist solid waste decision makers in determining the range of potential costs and associated GHG reductions for the diversion alternatives. The economic analysis will use the same geographic boundaries and specific diversion alternatives identified in the LCA effort. All facilities analyzed in the LCA effort will be included in the economic analysis subject to cost data availability and data quality.

The economic analysis will document and analyze the costs and economic impacts of the organic and recycling diversion scenarios. The cost results, in turn, will be incorporated, along with the LCA and GHG results, into the Customized California GHG Tool and our final report.

4.1 Boundaries Specific to the Economic Analysis

In addition to the boundaries discussed in the LCA, the economic analysis will be defined by the following parameters:

- Solid waste projections through 2025 – we will work with the Board to develop assumptions relative to expected growth in overall tonnage and changes in composition over the twenty-year projection period.

- Solid waste collection and transfer costs – in order to focus efforts on the economics of diversion alternatives, we plan to use a range of average costs per ton for solid waste, organics and recyclables collection and transfer costs gathered from existing data sources within each region, where available. The ranges will be defined by the collection type (e.g. single stream vs. source separated).

- Diversion alternatives costs and revenues – these costs and revenues will be determined for all of the diversion alternatives identified in the LCA task. Costs will include both operating and capital costs.

- Use of reported and published data – we are planning to derive cost, revenue and operating data based on survey data received from facility operators. Phone interviews will be used to verify and clarify data where necessary. Reported and published data will be used to provide perspective on the range of potential costs under varying assumptions and to provide supplemental data if needed.

- Return on investment for diversion alternatives is not included in the analysis.

- Number of facilities included in analysis – it is expected that, on average, three to seven facilities per diversion alternative will be analyzed in the cost analysis, subject to receipt of usable data. Regional differences will be identified for certain variables based on interviews with facility operators and will be factored into the analysis as appropriate.

- Cost effectiveness of the diversion options will be represented by a net cost per million metric ton CO_2 (\$/MMTCO_2) and net cost per ton diverted for the alternatives identified in the LCA effort. Specific assumptions used in the analysis are shown in **Table 7**.

- Cost savings/offsets will be analyzed and/or qualitatively described for each alternative from various perspectives including: municipality, agricultural community, and others. The final perspectives will be determined through data availability and Board discussion. We anticipate that the cost analysis portion of the GHG tool will be designed so that users will have flexibility in determining the appropriate offsets to incorporate into the analysis based on their perspective.

- Direct and indirect economic impacts will be analyzed through the use of Input/Output models for selected counties within each of the three regions as well as for the entire state. The results of this analysis will be presented in the final report but will not be directly incorporated into the GHG tool.

4.2 Key Assumptions and Methods Used in the Economic Analysis

Table 7 lists the key assumptions and methods that will be used in the cost analysis.

Table 7. Key Assumptions and Methods to be Used in the Cost Analysis

Variables	Value or Assumption	Notes on Methodology
Study Period	Calendar Year 2006 - Calendar Year 2025 (20 year study period)	Even though the target date is 2020, since we are evaluating various capital options, RTI would like to use a long enough time period to examine a reasonable service life for capital investment. Some facilities may be less than 20 years depending on the technology. RTI will start off with 20 years and re-examine this assumption as we collect more data.
Base Period	2006	RTI will be asking for calendar year 2006 data and if final 2007 data is available it will also be requested.
Solid Waste Projections	County and state tonnage by material type. County numbers will be compiled for the three regions.	See Section 2.4.

Variables	Value or Assumption	Notes on Methodology
Capital Costs (including Replacement Costs)	Costs incurred to obtain, construct, replace or refurbish an asset.	RTI will work with ARB in determining applicable assumptions used, if any, for projection of preliminary service life, capital cost, and replacement cost assumptions for equipment, vehicles, and facilities. Another source of this information is the facility operators.
Capital Financing Interest Rate	5.0% for loans.	A discount rate of 5% was used in the ARB report. May need to use a higher rate to reflect private financing costs if applicable. Will also discuss with facility operators financing options and available grants, if applicable.
Operating Expenses	Cost categories will vary by technology. However, the general cost categories will be as follows: ▪ Operating expenses from labor and benefits, ▪ Purchased supplies, ▪ Equipment and materials, ▪ Contractor costs, ▪ Utility costs, ▪ Feedstock costs, ▪ Environmental permitting and regulatory related costs, ▪ Administrative costs ▪ Closure and post-closure costs for landfills, ▪ Recovery and separation of materials, ▪ Disposal costs, and ▪ Treatment costs.	RTI will coordinate definitions of operating expenses with ARB as necessary. Projections for operating expense accounts will be developed using general inflation escalators, except for certain accounts such as electricity where a more exact escalator will be developed. Specific escalators will be developed as needed in consultation with facility operators and the Board staff.
Debt Service Expense	Principal and interest expense.	Existing debt service expense will be requested from facility operators. Projections for future debt service will be developed based on projected capital needs.
Revenues	Revenue categories may vary by technology, but will include: ▪ Electricity sales, ▪ Sales of organics by-products (i.e. compost), ▪ Sale of natural gas or vehicle fuel, ▪ Sale of recyclables recovered from the pre-processing of MSW (paper, glass, metals, plastics), ▪ Tipping fees, and ▪ Interest income.	RTI will work with ARB to make sure we are consistent with their assumptions for revenue projections.
Cost	▪ Water Savings in the form of avoided	If other costs savings/offsets are

Variables	Value or Assumption	Notes on Methodology
Savings/Offsets	water/irrigation purchases (kgals), ▪ Costs of Electricity Avoided ($/MWh), ▪ Revenues from Energy Generation ($/MWh), ▪ Avoided Disposal Costs, ▪ Avoided Fertilizer and Herbicide Costs, ▪ Reduced Virgin Inputs, ▪ Use of Other Materials Biofuels, ▪ Carbon Sequestration.	identified they will be included as applicable. It is anticipated that because the perspective of cost savings/offsets varies depending on the end-user of the GHG tool, we will represent these data for specific perspectives, e.g. composter, municipality, farmer, as applicable. We will work with the Board to determine the specific perspectives needed. The model will include options to select the type of user and will incorporate the appropriate offsets. Average regional commodity costs and prices will be used where applicable and available.
Cost Effectiveness	A range for $/MMTCO$_2$ and cost per ton diverted for each option over the 20 year time period will be calculated.	Options will be ranked from least to most expensive. The analysis will incorporate cost savings/offsets as chosen by the user.
Economic Impacts	▪ Primary impacts – employment (number of jobs), wages and direct output as measured in gross sales of organics diversion processing facilities. ▪ Secondary impacts – employment, wages and direct output in related industries. ▪ Economic multipliers – assessment of the impact of the organics diversion industry on income and jobs.	Input/Output models for selected counties and the state of California will be used to determine economic impacts. The models will be modified to more specifically incorporate the economic impacts of the various organics diversion options identified. For example, we will include specific information for the composting industry (e.g. annual sales and employment) in order to determine primary and secondary impacts of a particular organics diversion option.
Escalators	Operating and Capital Costs – California Consumer Price Index (CPI)	RTI will work with ARB to make sure we are consistent with their assumptions for price escalation.

5 GHG Tool

The goals/objectives of the GHG Tool are to develop a California-customized, user-friendly tool and a project report that can be used by the Board and other state users to assist in prioritizing organic diversion activities and in developing strategic directives for the state and for state regions, jurisdictions, and industries.

Our approach to developing the California-customized GHG Tool is to establish a clear definition of the goals and scope of the tool; define key features/requirements of the tool; compile key data and algorithms from the LCA and economic analysis components; prepare a stand-alone, easy-to-use application that enables users to modify key parameters that affect GHG emissions and emission reductions and economic outcomes for organic diversion alternatives;

perform testing and review of the tool; and prepare tool/system documentation and a user's manual.

A stand-alone design and requirements document for the GHG Tool is currently being prepared and will be distributed for review and comment in April 2009.